# Battlefield Optical Surveillance System (BOSS) -- A HMMWV Mounted System for Non-Lethal Point Defense[a]

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## I. INTRODUCTION

As the United States Armed Forces are increasingly asked to control world conflict through humanitarian and peacekeeping missions, nonlethal alternatives for applying force have spurred technologist to identify new methods for engaging potential adversaries. One promising technology comes from advancements in high power (1 to 10 watts) semiconductor lasers, lead by the United States Air Force Research Laboratory, Phillips Research Site. Semiconductor lasers have been fabricated to produce "high power" over the wavelength range 650 – 1550 nm for a variety of applications. The use of semiconductor lasers to illuminate potential adversaries was field tested during operation United Shield in Somolia in 1995. This deployment demonstrated two prototype visible illuminators – the Saber 203, and a diode-pumped, doubled Nd:YAG green laser, in addition to a fiber coupled near infrared (IR) illuminator system. The success of using semiconductor lasers as nonlethal weapons to detect, designate, and deter is the impetus for the Battlefield Optical Surveillance System (BOSS). This paper will present motivation for laser illumination systems, describe the BOSS in detail, present a notional operation scenario, provide laser eye-safety considerations and discuss the tested capability of the BOSS.

## II. MOTIVATION

Passive surveillance techniques in the near-IR (700 – 1000 nm) via "night vision" and silicon based detectors, and far IR (8 –12 μm) via thermal cameras that typically use HgCdTe detectors (also known as "forward looking infrared" or "FLIR"), have been used by the military and law enforcement since their introduction. Both technologies compliment each other but are limited under some conditions. One such condition is during very low light. Although the gain on a night vision tube is typically $10^4$, if the light is extremely low, the system is marginally effective.

One method to circumvent this shortcoming is to provide active illumination. Using semiconductor lasers, operators can illuminate in the near-IR or the visible depending on the need to operate covertly. Operation in the infrared allows the operator to remain completely covert to troops without night vision equipment, while visible illumination lets the targeted individual know that they have been spotted and are potentially facing a lethal response.

Use of visible lasers enables interaction with an adversary well outside small arms range, which provides a significantly safer environment for friendly troops. It also allows the adversary to be influenced without escalating the situation to lethal force. Jane's

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[a] This paper has been approved for public release by AFRL

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FIGURE 1

Defense weekly described the results that occurred with the use of a visible laser, the Saber 203, during the final withdrawal out of Somalia of UNITED SHIELD.

> "A Marine used the Saber 203 to "Light up" one member in the center of a hostile crowd in an effort to avoid lethal exchange when an armed Somali mob approached a US position. Seconds after the bright red pulse began to appear on the man's chest the mob had dispersed, leaving the "targeted" Somali standing alone."[3]

Visibly designating a potential adversary makes the situation personal for the illuminated individual and the laser removes anonymity and places responsibility for the escalation on the adversary's actions.[4] Lessons learned in Mogadishu regarding application of both visible and infrared illuminator systems led to the second-generation integrated platform, BOSS shown in Figure 1.

The BOSS system was developed with a number of different goals. First, a completely self contained, armored, mobile platform was needed to expand the employment tactics of lasers in combat. As a result, BOSS development was focused on creating a system that employed all the capabilities, and lessons learned, of the units initially deployed to Somalia but on a platform that was capable of rapid deployment and use with mobile units. Secondly, a system with greater power and range was needed to create an even greater standoff distance for friendly troops. With this greater power, however, came the need to properly evaluate and control eye safety issues. Extreme

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[3] "Less-Than-Lethal Weapons", Jane's Defense Weekly, 17 July 1996
[4] "Tactical Deployments of Lasers Into Low Intensity Conflicts" 96 IRIS Symposium

importance was placed on making an effective but safe system. Finally, new capabilities were to be designed into the BOSS that included sniper detection through Optical Augmentation. Optical Augmentation is the "cat-eye effect" or retroreflection that is a consequence of using active illumination. An experimental effort at the Air Force Research Laboratory, Phillips Research Site, has found that different optical systems will produce very distinct optical augmentation signals[5]. The addition of optical augmentation recognition adds yet another facet of performance for BOSS operators.

## III. SYSTEM DESCRIPTION

The imaging system consists of two FLIR Systems Inc. gimbals mounted on top of a hard top Highly Mobile Multi-Wheeled Vehicle (HMMWV), shown in Figure 2. One contains an 8-12 um FLIR and the other contains a long range LLTV (a night vision tube coupled with a camera is often referred to as a low light television or LLTV) camera system and two laser collimating lens. The LLTV gimbal is mounted above and behind the FLIR to give them the maximum field of view possible. There are three lasers built and integrated by Boeing located off gimbal in the rear of the HMMWV. The light is piped into the gimbal via fiber-optic cables. Both cameras can be viewed on two monitors mounted in front of the right rear seat shown in Figure 3.

The system is powered by a bank of lead acid batteries with a 3kw generator used for charging.

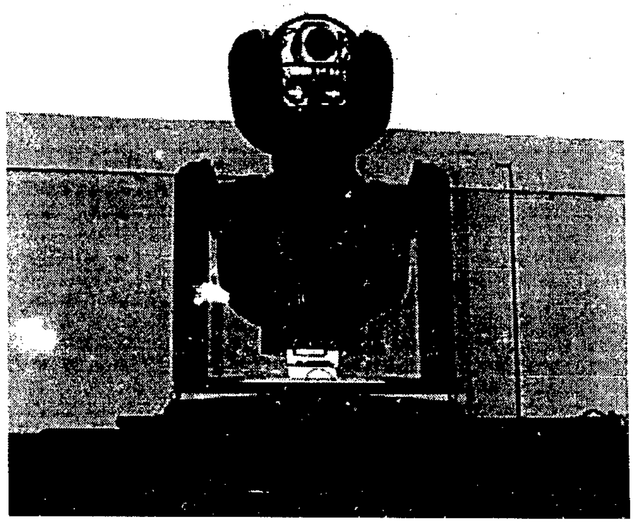

FIGURE 2

*Boss Gimbal System*

**FLIR** - The FLIR is an off the shelf FSI Safire cooled 8-12 μm imager. The FLIR system consists of the gimbal, control electronics box, hand control, and monitor. The

[5] S.Z. Peplinski and C.D. Lindstrom, "Non-Lethal Laser System for Sniper Detection via Optical Augmentation" NonLethal Defense III, 1998.

FLIR imager has two fields-of-view(FOV). The wide FOV is 28 x 16.8 degrees and the narrow FOV is 5 x 3 degrees. The imager is manipulated via a joystick on the hand control unit. It also has auto gain, video zoom, and some image processing.

**LLTV** - The second gimbal was purchased from FLIR Systems and the payload was assembled in-house from a combination of in-house fabricated and off the shelf components. The pointing and aiming controls and associated electronics for this gimbal are similar to the FLIR. The payload consists of a LLTV imager, two laser collimators, fiber-optic cables, and interface electronics. The LLTV imager and laser collimator lenses are mounted on a custom ring. The LLTV imager is centered in the upper portion of the ring and the laser collimator lenses are mounted below symmetrically. The controls for these components have been completely integrated into the FSI hand controller.

The LLTV imager is a combination CCD camera, Gen III intensifier, and 1000 mm zoom lens. The camera is a 1.5" square Sony CCD with a lux rating of .05 lux. The intensifier is a Litton 2400 Auto Day/Night CCTV Sensor. It has the ability in high ambient light conditions to switch out the intensifier tube and insert a relay lens so that a non- intensified image can be viewed. A light sensor allows this to happen automatically or there is a manual override to force it. The 1000 mm zoom lens is optimized for 800 nm light. It is continuously variable over a 500mm range and has a motorized doubler that can be remotely switched in.

The laser collimators are 65mm Rainbow motorized TV zoom lenses. A SMA to C-mount adapter allows the laser fiber to be mated to the lens. The zoom function of the lens allows the laser spot size to be varied. These lenses were selected because they were inexpensive and off-the-shelf technology.

*Lasers*

The three wavelengths available on the BOSS are 532nm, 670nm, and 810nm. The lasers can all be controlled from the front panel. They are all located off gimbal in the rear of the HMMWV. The light is piped to the gimbal via a 600um .37 NA fiber-optic cable. The lasers can all be remotely operated from the front panel.

**NIR Laser** - The near infrared laser(NIR) produces 810 nm light. It is a 20 watt GaAlAs diode laser bar that is fiber coupled. Losses associated with the fiber coupling cut power to 12 watts maximum at collimating lens. It is packaged along with power supplies, control electronics, and temperature controls in a 10" x 10" x 12" custom enclosure.

**RED Laser** - The 670 nm laser is a 3 watt GaAlAs laser. The power at the collimating lens is reduced to 1.5 watts due fiber coupling losses. It is packaged like the NIR laser.

**Green Laser** - The 532 nm laser is a diode pumped doubled Nd:YVO4 3 watt solid state laser made by Laser Power Corporation. The laser is fiber coupled which cuts the power to 1.5 watts at the collimating lens. It has been packaged into a larger enclosure to allow for a greater temperature range of operation, remote control, and fiber coupling.

FIGURE 3

## IV. OPERATION SCENARIO

The BOSS has several applicable missions including physical security, surveillance outpost, special operations, and law enforcement. The suite of equipment on board enable a progression of surveillance systems in addition to providing the user with the nonleathal capability that was found to be effective during Operation United Shield. Notionally, the 8 –12 μm camera is initially used for broad area passive surveillance. If the operator needs a closer look at potential targets, the FLIR can zoom in with a greater magnification. The near-IR spectral images can be viewed by slaving the CCD camera with night vision tube to the field of view of the FLIR. If the ambient light conditions are very low, or if the user wishes to designate the target for night vision equipped friendly troops, he can illuminate the target with the near-IR laser. The beam divergence is easily controlled to either operate with a large beam divergence for broad area operation, or a narrower beam divergence for target designation. Depending on the threat level, BOSS can then operate as a nonlethal weapon system by illuminating a potential adversary overtly by using one of the visible lasers on board.

Another relevant mission for BOSS is sniper detection. The operator may also use the active illumination capability to search for optical components in the field of view by exploiting the optical return or optical augmentation (OA) characteristics of optical components. The principles of OA are described in detail elsewhere.

## V. LASER EYE-SAFETY

Laser eye safety standards exposure are outlined by ANSI-Z136.1-1993 which draw upon a significant number of experimental tests. Because all three lasers on the BOSS are continuous wave (cw) rather than pulsed systems, the ANSI standard is straightforward to understand. For visible lasers the "blink response time" is assumed to be 0.25 sec, thus for the green 532nm and the red 670nm, the maximum permissible exposure (MPE) is 2.55 mW/cm$^2$. In the case of the near-IR laser, the MPE is modified by a coefficient, referred to as $C_A$ by ANSI, which accounts for the retina's decreased absorption in the near IR. The near-IR laser used in the BOSS system is at 808 nm, which according to ANSI increases the MPE by 1.644 times over the visible MPE. The blink response time for invisible radiation, including the IR, is simply the average time between blinks, which according to ANSI is 10 sec. The potential for increased retinal exposure is accounted for in ANSI by the relation $t^{1/4}$, where "t" is the exposure duration. Thus, the MPE for IR radiation is multiplied by $(1/40)^{1/4} = 0.398$ resulting in the MPE for our near IR laser is MPE(808nm) = 1.664 mW/cm$^2$.

Given the MPE, eye safety consideration now becomes a function of beam characteristics and geometry. One important beam characteristic is the homogeneity of the beam profile. Any "hot-spots" in the beam will dictate the total laser power as driven by eye safety considerations. Because the lasers are fiber coupled via 600 μm multi-mode fibers from inside the HMMWV up to the exit optic on the gimbal, the number of modes in the fiber drives the beam quality and homogeneity. The fibers used in the BOSS support well over $10^4$ modes for each wavelength resulting in poor beam quality, a wave front that is no longer in phase, and excellent homogeneity.

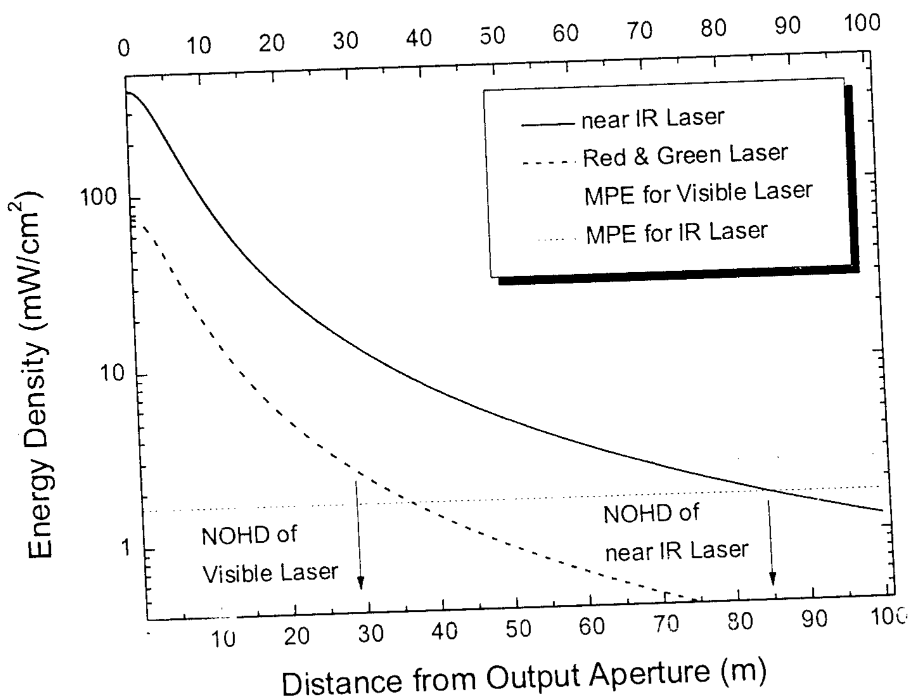


FIGURE 4

The maximum power possible from the near-IR, 670nm, and 532nm lasers are 8 watts, 1.5 watts, and 1.5 watts respectively. The exit apertures for the lasers are each 2 inches. The smallest divergence we are capable of with the 600 μm fiber and a 65 mm focal length lens is 10 m diameter spot at 1 km or approximately 10 mrad. Given this divergence, the nominal ocular hazard distance (NOHD) as defined by ANSI for the 532nm, 670nm and 808nm lasers are 29, 29, and 85 meters respectively. In operation, the

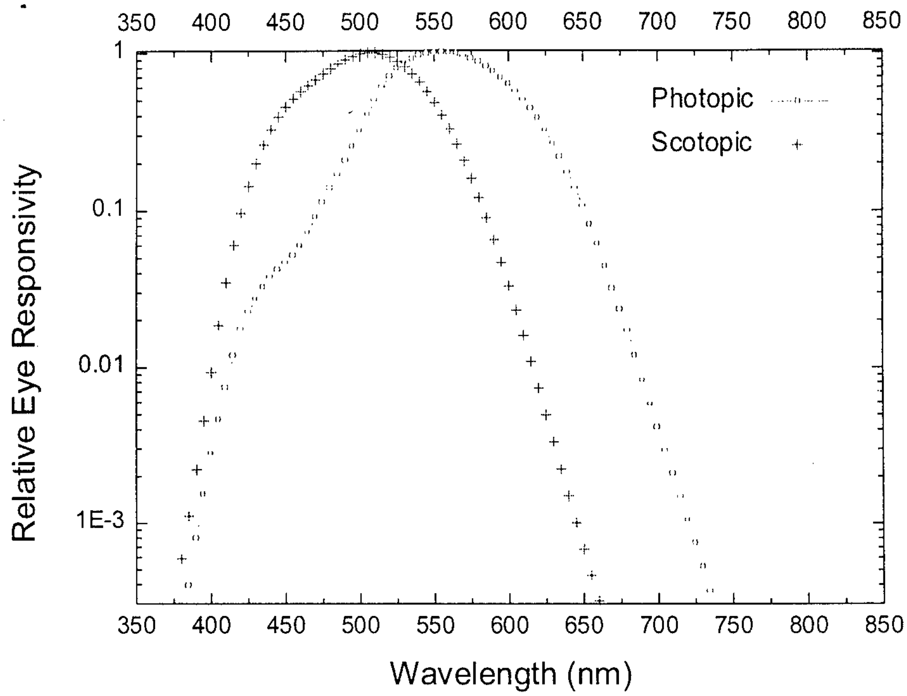


FIGURE 5

BOSS minimum engagement range is 100 meters, thus insuring compliance with ANSI eye safety guidelines. A plot of the optical intensity as a function of distance is shown in Figure 4, along with the MPE levels for the visible and IR laser wavelengths.

The ANSI standard guidelines were developed for inadvertent or unintentional exposure to lasers. At the time of this paper, no clear guidance exists for intentional exposure by nonlethal laser illuminator weapons. The only potential modification for intentional exposure versus unintentional is in the amount of time an individual would likely look directly into the laser without moving the eye. It is important to bear in mind three things with regard to this distinction. First, the cumulative eye safety consideration associated with exposure duration is only weakly related, given by $(\text{time})^{1/4}$. Second, the individual being exposed must maintain a motionless eye for cumulative effects to potentially cause any damage. Third, the calculations presented here are for the worst possible case with regard to laser power and beam geometry.

It is also worth noting at this point the sensitivity of the eye as a function of wavelength for both light adapted, photopic, and dark adapted, scotopic, vision. This information is readily available on the World Wide Web at http://cvision.ucsd.edu and is plotted in Figure 5. The motivation to use 532 nm over 670 nm for nonlethal engagement is readily apparent from this plot. For scotopic vision, the eye is over 5000 times more sensitive to 530nm than to 670nm, and 25 times more sensitive for photopic vision.

## VI. CAPABILITY

The combination of active LLTV and FLIR give the BOSS the ability detect, assess, and deter possible threats at a standoff range of greater then 1 km in any ambient lighting conditions. The FLIR can readily detect heat signatures, under typical conditions, the size of a man at 1 km in wide FOV. It may be possible for hostile personnel to hide behind and in obstructions to hide their thermal signature, but if they use any optics to observe the BOSS's position, BOSS operators using any of the three lasers can detect them. The operator of the BOSS will see a bright flash on the monitor screen and know immediately that there is a sophisticated threat. Once the threat is detected the operator can then zoom in with the LLTV to assess the level of reaction required. The visible lasers can then be activated to designate the target. This beam will immediately communicate to friendly forces the location of the threat and if warranted, lethal force can be applied.

## VII. SUMMARY

In the past, American troops had little choice for nonlethal detection, deterrence, and designation – not so anymore. With the technological advancements in high power semiconductor laser technology, lead by the United States Air Force Research Laboratory, Phillips Research Site, American soldiers now have the capability to take nonlethal action in situations that before were only possible through lethal means. As a result of today's warfighter's needs and the roles America will ask the armed forces to play, development of a comprehensive system for night time surveillance and deterrence is vital to successful control of the battlefield – BOSS is that system. This effort was funded by DARPA – Counter Sniper Office.